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INVESTIGATING THE LIKELIHOOD OF CATASTROPHIC EVENTS IN NATURAL GAS PIPELINES USING AN INTEGRATION OF FAULT TREE ANALYSIS AND WHAT-IF METHODS

UDK 622.691:364.254]: 519.226
RECEIVED: 2015-09-02
ACCEPTED: 2016-01-04

SUMMARY: Today, natural gas is considered the biggest source of supplying the energy required by many residential and industrial areas. A look at the technologies available in Iran makes it evident that pipelines are the best and safest way for the country to carry and distribute natural gas. This energy resource, which is sometimes referred to as clean fuel, plays a strategic role in providing required energy. On the other hand, this fuel must be supplied in a continuous and yet safe manner. Hence, we arrive to the conclusion that appropriate measures are needed to be taken to manage the risks involved in leakage, firing and explosion in these facilities. To meet the goal, it is very necessary to probe into the reasons of catastrophes and examine reliability issues. Also, it is inevitable for us to estimate the likelihood of catastrophes in these pipelines. One of the essential steps of risk evaluation process is to estimate the likelihood of potential catastrophes. This paper adopts FTA methodology to study the process of catastrophes likelihood estimation in natural gas pipelines. Also, a novel method is provided here which is based on assigning weights to fault tree and "What-if" scenario is used to identify the hazards involved in carrying natural gas from its main source. Based on the results obtained in the study, we propose to control the likelihood of catastrophes occurrence in natural gas pipelines using a technical and systematic approach in which the underlying causes of these catastrophes are identified and controlled..

Key words: *catastrophes likelihood, reliability, underlying causes of catastrophes, ALOHA software, jet fire scenario*

INTRODUCTION

Natural gas pipelines fall into three groups: collection pipelines, carrying pipelines and distribution pipelines. Collection pipelines convey gas from the cap of the wells to storage centers. These groups of pipelines have mostly low pressure with very low likelihood rate for catastrophes incidence. Natural gas is carried through carrying lines from storage centers to refineries to get refined. Then, this gas is carried to distribution network to be supplied for residential and industrial centers *(Ambituuni et al, 2015).*

These carrying lines pass through different areas like oasis, deserts, fields, mountainous areas and sometimes from neighborhood of rural lands and agricultural lands. While passing these areas, they are mostly buried under the ground. In contrast to carrying lines, the pipelines of distribution network passes through highly populated and often urban areas, while they are sometimes buried underground. They exposes significant risk in terms of firing and explosion. The rate of catastrophes in distribution pipelines

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is higher than that of other groups of pipelines, such that carrying and collection pipelines are ranked in the second and third place in terms of these risks, respectively *(U.K. Health and Safety Executive, 2000)*.

Currently, natural gas is the mostly used fuel and energy source in residential and industrial areas. Equipped to this knowledge, it can be proposed that any catastrophe in these pipelines and any disturbance in safe and continuous supplying of natural gas will bring about negative outcomes. These catastrophes not only risk the life of the companies personnel and employees as well as those people which are in the neighborhood of these pipelines and bring about damages to facilities, but disturb the daily lives of people and interrupt the functions of industrial centers. To get a little technical, these catastrophes create energy crisis. In the event that catastrophe happens in international pipelines used for gas export, it not only causes direct damages, but discredits the supplying companies and their ability to act their responsibilities. Thus, taking risk control measures for gas pipelines is completely necessary and essential. To lower the risks the pipelines are exposed to, either the intensity of the implications of these incidences must be reduced, or the probability of the incidences must be lowered. The current study, tries to approach the risk control through the second strategy, i.e. decreasing the likelihood of these negative incidences *(Thomas & Dawe, 2003, Jo & Crawl, 2008)*.

FTA (Fault Tree Analysis) is a semi-quantitative method through which the underlying causes of and incidence can be attributed to the top event *(Dhillon, 2008)*. Therefore, the likelihood of events can be reduced through controlling the underlying causes. Using this method, it is possible, for instance, to estimate how the likelihood of incidence in the pipeline is reduced as the pipelines condition undergoes a certain change. Note that, the catastrophe likelihood varies for different parts of pipelines. To examine this, firstly a pipeline must be divided into its constituent parts, such that each part has the same condition. The steps of Risk analysis by FTA method have been show in Fig. 1 *(Vinnem, 2013)*.

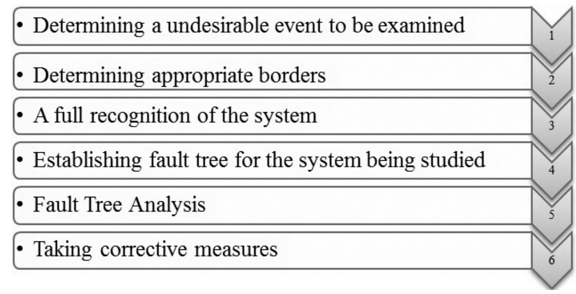


Figure. 1. The steps of Risk analysis using FTA method

Slika 1. Faze analize rizika pomoću FTA metode

METHODOLOGY

In this study, firstly expected scenarios and catastrophes are identified for a given gas pipelines facility and then the reasons and factors behind these catastrophes are examined. Finally, the procedure used to estimate the likelihood of the events is investigated using FTA method. To elaborate, the current research study uses FTA method to attribute logically the underlying factors of the events to top implications and the identified scenarios.

Identifying credible scenarios

We used ALOHA (Areal Locations of Hazardous Atmospheres) software to identify the scenarios and examine their implications. In this step, gas pipelines are divided into three groups: a) collection pipelines, b) carrying pipelines, and c) distribution pipelines. Then, for each group of pipelines, the input information was provided for the software based on the characteristics of each group. Credible scenarios were recognized based on the output models.

Identifying risks of incidence and underlying factors

Although FTA method is itself an appropriate method to identify the risks *(Vinnem, 2013)*, but "what-if" method is suggested for the case of gas pipelines. This non-systematic methodology takes less time compared to other methods to identify the risks and doesn't require significant expertise. It is a flexible method through which combinations of failures can be examined

(Dennis & Nolan, 1994). If a full-blown and well-informed "what-if" methodology is implemented for gas pipelines, a complete checklist can be designed. This checklist can be later used for ever to identify risks in various parts of gas pipelines. "What-if" methodology is mainly based on brainstorming sessions, discussion and interaction *(Dennis & Nolan, 1994).*

Incidence likelihood

As suggested, FTA method is not used in this research to identify the risks rather FTA algorithm is used along with "what-if" methodology to estimate the likelihood of catastrophes. To this end, various mathematical formulations and probability rules are employed.

SCENARIO DISCUSSION

In order to use FTA methodology, it is needed to firstly identify incidences and their final implications. Expected scenarios vary for each system, depending on its conditions and characteristics. For instance, it doesn't make sense to consider pool firing for a gas reservoir or a gas pipeline. However, it is not always so easy to identify the expected scenarios, because they depend on different situations. To this end, historical data of the system must also be considered.

Based on the models developed using ALOHA software, it is very unlikely for the incidences resulted from the following scenarios to occur: 1: Gas toxicity effect (Fig. 2), 2: Flash fire (Fig. 3). The likelihood of these scenarios can be neglected. These are resulted from the nature and characteristics of natural gas. However, the concentration of H2S is high in pipelines that convey sour gas. This is the case with gas collection pipelines in the southern part of Iran which must be taken into consideration as a factor that increase the toxicity of natural gas. Additionally, although natural gas is free of toxicity property, but long term exposure to the material and decrease in oxygen concentration because of gas leakage may leave health problems in individuals. Generally, based on historical data obtained for pipelines system, toxicity and flash fire scenarios can be neglected *(Vianello & Maschio, 2014)*.

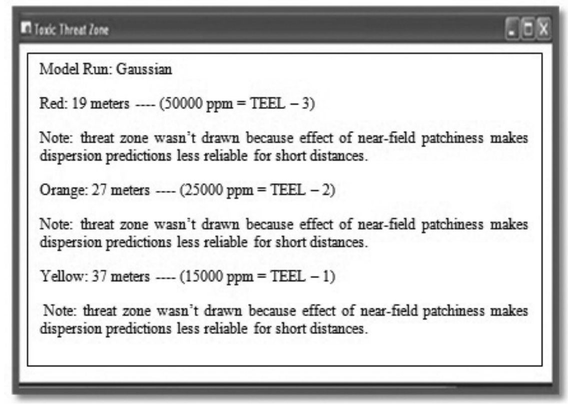


Figure 2. Output model of ALOHA for toxicity effect of natural gas in a 60 psi pipeline

Slika 2. Izlazni model prema ALOHI za učinke toksičnosti prirodnog plina na cjevovodu 60 psi

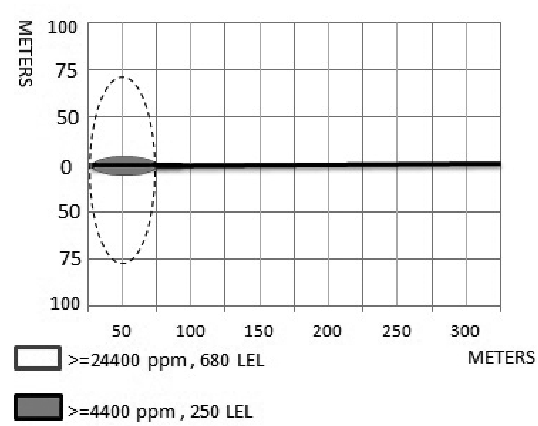


Figure 3. Output model of ALOHA for flash fire effect in 60 psi pipeline

Slika 3. Izlazni model prema ALOHI za bukteći požar na cjevovodu 60 psi

Based on output models obtained by ALOHA software and the information gathered about recent incidences, the most important expected scenarios in gas pipelines are as follows:

A. Jet fire: this happens when a flammable chemical is rapidly passing through a hole created on a container, leading it to be ignited just there. The shape of the resulted flame is similar to welding flame. The most important danger caused by jet fire is its thermal radiation *(ALOHA user's manual, 2002)*. In the case of natural gas pipelines, when the rate of gas leakage is high and output gas is ignited for any reason like the spark caused by mechanical strike on the pipeline, jet fire scenario is expected (Fig. 4).

B. Vapor cloud explosion: this scenario happens when the gas is not ignited, once it exits the hole and is conveyed into an inbound environment like surrounding buildings through wind flow and accumulated there. In time, the gas concentration rises in this place reaching to a ignitable level (Fig. 5). At this point, an energy source like electrical appliances may create a spark leading to the explosion of the gas with a high intensity. The significant energy resulted from this explosion creates energy waves and thermal radiation and throws explosion materials around. This will result in damages to facilities and individuals. Those surrounding buildings that are within Lower Flammability Limit (LFL) may be damaged considerably as a result of vapor cloud explosion *(Jo & Ahn, 1994)*.

Note that the procedure for examining the underlying causes of these two scenarios is completely similar. However, these causes in the scenarios may vary to some extent for different incidences. For instance, consider a case in which the incidence is caused by sabotage organized operation and evil actions involving implanting bombs and explosives. Jet fire is the expected scenario for these cases. In the case of bed super vapor explosion, taking this case as the cause of catastrophe, may lead to wrong estimation of the likelihood of this scenario. Taken this, in order to use FTA method, it is suggested to firstly identify scenarios for other systems and calculate the likelihood for each scenario separately. Having determined the likelihood of catastrophe for each scenario, we can use mathematics and probability relationships to calculate the overall likelihood of incidence.

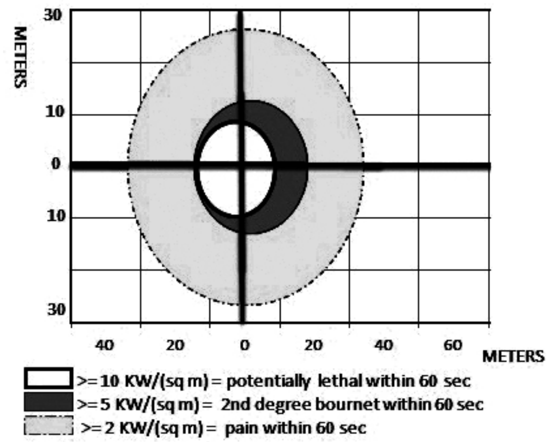


Figure 4. Output model of ALOHA software for jet fire in 6 psi pipeline

Slika 4. Izlazni model prema ALOHI za mlazni požar na cjevovodu 6 psi

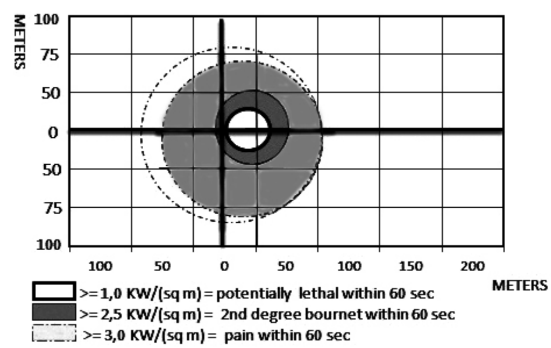


Figure 5. Output model of ALOHA software for jet fire in 60 psi pipeline

Slika 5. Izlazni model prema ALOHI za mlazni požar na cjevovodu 60 psi

Identified risks (hazards)

As mentioned before, we used "what-if" methodology to identify the risks involved in gas pipelines. The procedure for identifying the risks in a given system using the method is as follows *(Dennis & Nolan, 1994)*:

1. Define hypotheses for the set which are acceptable during the process.
2. Define borders and operational states for the set which is being studied.
3. Select and verify the range of a node. [a system must be split into smaller pieces]

4. Explain the overall objectives of the design and operational condition of the node.
5. Determine process parameters of nodes.
6. Propose a "what-if" question.
7. Identify all risk scenarios through "what-if" question.
8. Repeat the above procedure for other "what-if" questions.
9. Repeat the above procedure for other nodes.

However, in order to identify the significant and important identified risks, a risk analysis may be required. This analysis must involve an estimation of likelihood and the intensity of each implication of the expected incidences for each risk.

Most important risks for natural gas pipelines identified using this method are as follows:

- Applying mechanical strokes and damages to pipelines as a result of external interventions and unauthorized diggings.
- A variety of erosion that may be originated from failure in protective methods, like using inappropriate covers or materials for manufacturing pipes.
- Erosion in pipelines that usually are resulted from the presence of impurities in natural gas. Also, external erosion may be caused by the flow of floodwater over the pipelines or earth which removes outer coverage of the pipe and decreases the thickness of the pipes.
- Land slide
- Sabotage, evil actions and terrorism
- Explosion or jet fire in another pipeline which is in neighborhood of the given pipeline
- The presence of a fault in implementing hydrostatic test or applying the pressures that are higher than maximum allowable pressure in the pipelines
- Explosion and overall rupture in a part of pipeline which might be resulted from the formation and the spread of a crack, volume defects or unsuitable welding
- The presence of a fault in HOT TAP operations
- Fatigue which might be caused by of fluctuations in pipelines
- Static electricity built up in poly-ethylene pipelines (in distribution network)

The procedure of estimating catastrophes likelihood

Generally, influential factors in likelihood of catastrophes or the underlying causes of the incidences are classified into five groups, as shown in (Figure 6). Each risk identified in this section belongs to one of these groups. Also, each of these classes or groups is influenced by special actions and conditions which are examined and weighted in FTA method.

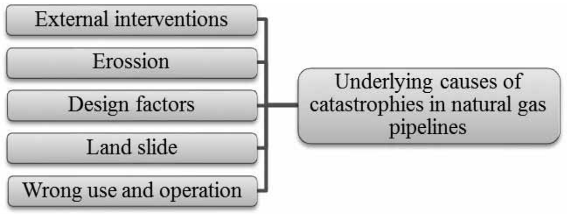


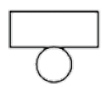
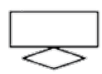
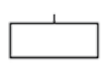
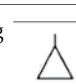
Figure 6. Influential factors in likelihood of catastrophes

Slika 6. Čimbenici koji utječu na vjerojatnost nesreće

Particular symbols and shapes are used in FTA methodology to represent underlying causes of incidences and estimate the likelihood of the top event, as are explained if (Table 1).

Table 1. Symbols and shapes used in FTA methodology

Tablica 1. Znakovi i oblici koji se koriste u FTA metodologiji

Logic gates	 "OR" gate	"OR" gate - indikates if any input incidences happen, the output incidence will happen as well
	 "AND" gate	"AND" gate - indicates that the output incidence will happen only if all the input incidences happen simultaneously
Input incidences (states)		(Initial incidence) Represents a fundamental fault in the tools which doesn´t need any extension and investigation
		(Unexamined incidence) Represents an incidence that has not been investigate more due to the lack of access to information or the fact that the implications of the incidence are not important
Explanation about a give state		(Explanation rectangle) is used for providing complementary information
Carryng symbols	Outgoing carrying  Incoming carrying 	(Outgoing carrying) symbol indicates that the fault tree has been investigated more in the symbol place (incoming carrying)

Estimating the likelihood of jet fire scenario

This section employs the data obtained about underlying causes of incidences to study partially the procedure of investigating the underlying causes of catastrophes and estimating the likelihood of the top event. As the paper doesn't afford to include all aforementioned scenarios, jet fire scenario is only investigated. In this scenario, we examine where "external intervention" factor originates to find underlying causes and finally examine formula and logic relationships used in FTA method. The similar procedure can be used to identify underlying causes of other factors including erosion, design factors, land slide, fault in operations and inappropriate uses. Additionally, the similar procedure is repeated for the scenario of bed super vapor explosion.

The following three step process is suggested to calculate the likelihood of an incidence using FTA methodology:

1. Assigning weights to those sections that multiple input with "OR" gate is connected to one output.
2. Estimating the incidence likelihood for underlying causes based on the system condition and historical data.
3. Summarizing probabilities and using probability rules from top to bottom to obtain the likelihood of the main scenario.

In the first step, the influence of each input on outputs is investigated and the fault tree is weighted. Historical data and previous experiences can be used to assign weights or this may be achieved using indices provided in reference books and handbooks. As the probability must be less than 1, the weighting must be performed in a way that the sum of the weights assigned to inputs will be equal to 1. The likelihood of each input is multiplied by to the weight assigned to the input. Finally, these values add up to give us the likelihood of a given output incidence. This process is much similar to the way we calculate weighted average. Historical data can be considered in calculating probability of incidences. A sample weighting of the tree is sown in (Fig. 7).

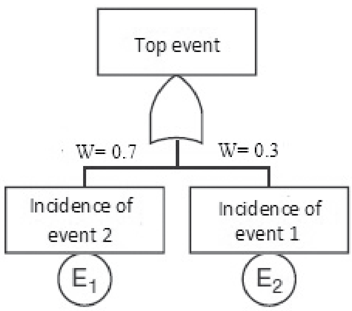


Figure 7. A sample of weighting tree for those inputs that are connected to output using "OR" gate

Slika 7. Primjer težinskog stabla za ulaze povezane s izlazom pomoću 'ILI' sklopa

This weighting process indicates that the incidence of the top event is 30% dependent to incidence of event 1, while its dependency to event 2 is 70%. The sum of assigned weights is equal to 1. If more than 2 inputs are present, again the sum of weights must be equal to 1.

In the second and third steps, the likelihood of catastrophes is examined from bottom to top. Then, based on assigned weights and "intersection" and "union" rules in probability discussion, the likelihood of the top event is estimated.

Based on intersection rule, if multiple inputs are connected to output using "AND" gate, then the likelihood of output incidence is equal to the product of likelihood of inputs incidence (this rule holds if inputs are independent from each other). As the probability assigned o each input is less than 1, the product of the likelihood of inputs will be reliably less than 1. The probability relationship for those inputs that are connected to output using an "AND" gate is as follows *(Jo & Crowl, 2008)*:

$$P(X) = \prod_{i=1}^{m} P(x_i) \quad (1)$$

Where m is the number of independent inputs of "AND" gate, x_i values are inputs of "AND" gate for i=1,2,3,..., m and *P* (x_i) is the likelihood of the incidence of input x_i. Finally, P(X) is the likelihood of output incidence of the gate.

Based on union rule, if multiple inputs are connected to a single output through "OR" gate, the likelihood of the occurrence of the output is equal to the sum of the likelihood of the inputs (note that all the inputs must be mutually exclusive. That is, their intersection must be null) *(Ross, 2014)*. Overall likelihood of independent inputs that are connected to output through "OR" gate is determined through the following relationship *(Jo & Crowl, 2008):*

$$P(Y) = 1 - \prod_{i=1}^{k} \{1 - P(y_i)\} \quad (2)$$

Where k is the total number of independent inputs of "OR" gate, y_t values are the input of "OR" gate for i=1,2,3,..., k and $P(y_t)$ is the likelihood of the incidence of input y_t. Finally, *P(Y)* is the likelihood of the occurance of the gate output?

In this formula, the inputs are considered to be independent. Not any two inputs can be independent and mutually exclusive simultaneously. In real situation, especially when there are many inputs, it may not be clear whether inputs are independent or mutually exclusive. This formula holds true if all the inputs belong to a universal set and the relationship between these inputs is completely clear. Using abstract mathematical relationships creates ambiguity and wastes the time. This formula is not used in our proposed methodology, rather the likelihood of each input is multiplied by its weight and then the sum of these weighted products is determined as the output likelihood. So, this weighting procedure is performed based on historical data of the system to limit the influence of each input in output incidence to a maximum value (i.e. the assigned weight). This method can be used in all cases.

In weighting process and using "OR" gate, if the value of and input is known as percentage, this value is divided by 100 and multiplied by the assigned weight to obtain a desirable value. This value represents how this input affects output. For instance, if the likelihood of the incidence of an input is equal to 90 percent and its assigned weight is equal to 0.2, the effect of this input on output is calculated using the following relationship:

$$\text{Input influence} = \frac{90}{100} \times 0.2 = 0.18 \qquad (3)$$

The same procedure is repeated for other inputs, adding these numbers to obtain the likelihood of output incidence. All the calculated probabilities will be positive and less than 1.

The given pipeline can be split into a set of sections in order to determine the risk involved in each section separately. As the length of each section is known, we need only to consider a suitable temporal base to estimate the probability of an incidence. For instance, suppose that the length of a section of a given pipeline is equal to 1 kilometer and historical data indicate that 5 days out of 365 days of a year, a land slide is likely in this section of the pipeline. In this case, the likelihood of land slide in this section is about 1.37 percent or 0.0137. Other calculations follow the same procedure. To interpret the calculated likelihoods, both one kilometer base and 365 days of the year must be taken into consideration. For instance, if the calculation process in the fault tree leads to the value of 0.06 for the likelihood of the top event, it means that catastrophe is expected to happen in about 22 days of a year in the given one kilometer section of the pipeline.

We have supposed in this three step process that the inputs connected to output using "AND" gate are independent from each other. To have a more precise estimation of the main scenario, it is advisable to design the fault tree in a way that this assumption holds.

The fault tree for jet fire scenario is depicted in Fig. 8. The calculations are started from the lowest part of the tree. As already mentioned, the pipeline must be split into a set of sections to examine the likelihood of catastrophe and the risk involved in gas pipelines *(Muhlbauer, 2004)*. If we consider a particular part of the pipeline, the following formulation can be proposed for "external interventions".

Note that in these formulations, P (a) represents the likelihood of event a. Referring to Fig. 8 and the weights assigned in the fault tree denoted with W symbol, the following formulations are driven:

If:

$P(F1) = 0.2, P(F2) = 0.6, P(F3) = 0.4$

Then:

$P(E3) = W17 \times P(F1) + W18 \times P(F2) \times W19 \times P(F3)$

$\Rightarrow P(E3) = 0.3 \times 0.2 + 0.4 \times 0.6 + 0.3 \times 0.4 = 0.42$

Similarly, if:

$P(E1) = 0.01,\ P(E2) = 0.1,\ P(E4) = 0.1,\ P(E5) = 0.9,\ P(E6) = 0.4,\ P(E7) = 0.02,\ P(E8) = 0.7$

Then:

$P(C3) = P(E1) \times W9 + P(E2) \times W10 + P(E3) \times W11 + P(E4) \times W12 + P(E5) \times W(13) + E6 \times W14 + P(E4) + P(E7) \times W15 + P(E8) \times W16$

$\Rightarrow P(C3) = 0.01 \times 0.1 + 0.1 \times 0.2 + 0.42 \times 0.1 + 0.1 \times 0.1 + 0.9 \times 0.1 + 0.4 \times 0.1 + 0.02 \times 0.05 + 0.7 \times 0.25 \cong 0.38$

Additionally, we suppose that the likelihood of spark in leakage area is 50 percent for inadvertent interventions. Then, $P(C4)=0.5$, because C3 and C4 are connected to B2 using "AND" gate. Now, we use mathematical sets intersection rule:

$P(B2) = P(C3) \times P(C4) = 0.38 \times 0.5 = 0.19$

We proceed to other parts of the tree:

If:

$P(D1) = 0.5,\ P(D2) = 0.8,\ P(D3) = 0.1$

Then:

$P(C1) = P(D1) \times P(D2) \times P(D3) = 0.04$

In deliberate sabotage, the likelihood of spark is approximately 100 percent. So, P(C2) can be assumed to be equal to 1. Then,

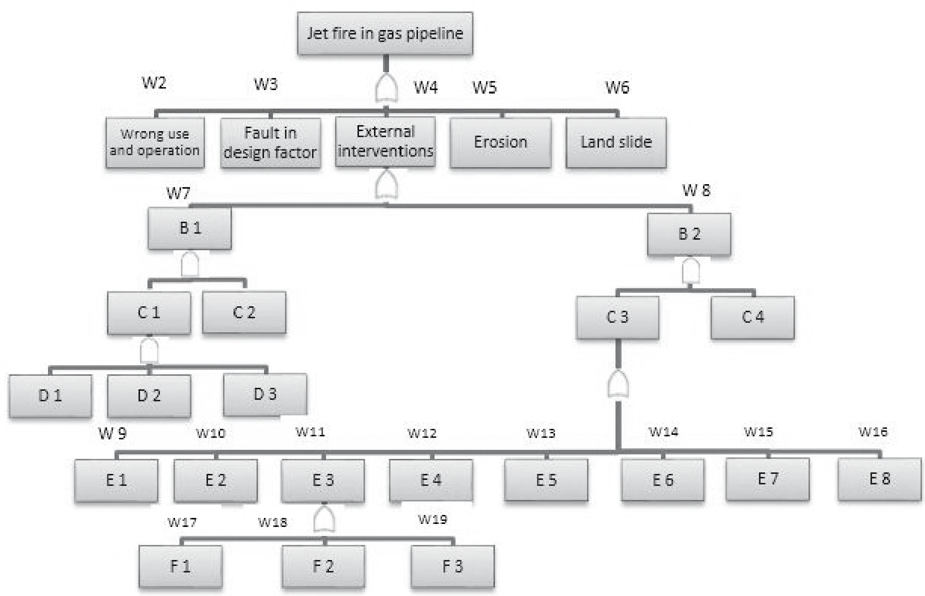
$P(B1) = P(C1) \times P(C2) = 0.04 \times 1.00 = 0.04$

Having calculated these values, the likelihood of catastrophe resulted from external interventions (L) is obtained:

$P(L) = P(B1) \times W7 + P(B2) \times W8 = 0.04 \times 0.5 + 0.19 \times 0.5 \cong 0.12$

Repeating the same procedure for other factors, we can easily obtain erosion likelihood (M), land slide likelihood (N), the likelihood of fault in design factors (O), and the likelihood of inappropriate use and operation (P). Finally, the likelihood of jet fire scenario (X1) for a given section is estimated using the following relationship:

$P(X1) = P(L) \times W4 + P(M) \times W5 + P(N) \times W6 + P(O) \times W3 + P(P) \times W2$



Values of W: W2=0.12 ،W3=0.18 ،W4=0.16 ،W5=0.47 ،W6=0.07 ،W7=0.5 ،W8=0.5 ،W9=0.1 ، W10=0.2 ،W11=0.1 ،W12=0.1 ،W13=0.1 ،W14=0.1 ،W15=0.05 ،W16=0.25 ، W17=0.3 ،W18= 0.4 ،W19=0.3

B 1	Deliberate interventions	E 2	Inobservance to principles of pipelines burial like shallow burial
B 2	Inadvertent interventions	E 3	Burial of pipelines in areas with high activity load
C 1	Sabotage, evil activities and terrorism	E 4	Infrequency of patrols
C 2	Likelihood of spark in leakage area	E 5	Insufficiency of educational plans for public
C 3	Inadvertent interventions leading to gas leakage	E 6	Fault in locating of buried pipeline
C 4	Likelihood of spark in leakage area	E 7	Unspecified the place of pipeline
D 1	Infrequency of patrols	E 8	Unauthorized diggings
D 2	Inefficiency of protection systems	F 1	Burial of pipelines in areas which are under construction
D 3	Likelihood of political unrest and strategic position of given pipeline	F 2	Burial of pipelines near other buried pipelines and facilities
E 1	Inefficient protection of surface facilities	F 3	Burial of pipelines in highly populated areas with high traffic level

Figure 8. Fault tree for Jet fire scenario, with identification of underlying causes of "external interventions"

Slika 8. Stablo kvarova za scenarij mlaznog požara, s utvrđenim uzrocima "vanjskih intervencija"

CONCLUSION AND RESULT

This paper adopts FTA methodology to study the process of catastrophes likelihood estimation in natural gas pipelines. Also, a novel method is provided here which is based on assigning weights to fault tree and "What-if" scenario is used to identify the hazards involved in carrying natural gas from its main source. Based on the results obtained in the study, we propose to control the likelihood of catastrophes occurrence in natural gas pipelines using a technical and systematic approach in which the underlying causes of these catastrophes are identified and controlled.

Fault tree analysis (FTA) is a very powerful technique and widely used for evaluating the safety and reliability of complex system and oil-gas pipeline *(Markowski, 2012)*. According to the study conducted by DONG Yu-hua, et al, A 52 minimal cut sets have been achieved with qualitative analysis, while the failure probability of top event and the criticality analysis of basic events could be calculated with quantitative analysis, based on this study Fault tree analysis (FTA) is a very powerful technique and widely used for evaluating the safety and reliability of complex system. The failure of oil and gas pipeline was analyzed by fault tree analysis in this paper *(Yu-hua, 2002)*.

In the modern petroleum industry, pipeline is one of the safest and the most economical methods to transport lager quantities of oil and natural gas, On the basis of investigating and studying, taking "gas pipeline be damaged by third-party interference" as top event and considering 31 basic events, a relatively integrated fault tree model is established. Then the results of qualitative analysis on this fault tree are discussed *(Liang et al., 2011)*. According to the study conducted by ZHENG Xian-bin and et al., showed that The combination method of fault tree analysis and fuzzy comprehensive evaluation method was proposed to make research of oil and gas pipeline failure and result indicates that the FTA method makes full use of their advantages and controls their disadvantages, and is feasible to evaluate the oil and Gas pipeline failure based on this study The result indicates that the method makes full use of their advantages and controls their disadvantages, and is feasible to evaluate the oil and Gas pipeline failure *(Zheng & Guoming, 2005)*.

Today, it is no longer possible to predict future conditions of real world using simple and abstract mathematical relations. It seemed that probability distribution cannot account for underlying causes of human-induced errors, safety culture and similar subjects. Using mathematical relationships may take a lot of time and lead us astray, if historical data and the information about the background of a system obtained through observations and measurement are not used. In modern world, the emergence of fuzzy logic on one hand and the fact that many researchers tend to use knowledge based calculations on another hand indicate the inefficiency of some mathematical relationships and the rules and techniques of probability science in explaining the complex conditions of real word. This research paper places emphasis on historical data in examining the probability of catastrophes likelihood in natural gas pipelines. To meet this requirement, historical data were used in software, mathematical and logical calculations to identify credible scenarios, risks and fault tree analysis. Based on the results obtained through this research, several steps can be taken to provide a framework based on experiments and mathematical to examine and estimate the likelihood of catastrophes incidence in natural gas pipelines. These steps include using catastrophe modeling software with historical data, identification of risks using "what-if" methodology, establishment of fault tree and assigning weights to it based on historical data and finally implementing FTA methodology and analyzing it using formulations provided in this research.

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ISPITIVANJE VJEROJATNOSTI NESREĆA NA CJEVOVODIMA ZA PRIRODNI PLIN METODOM INTEGRACIJE ANALIZE STABLA KVAROVA I WHAT-IF SCENARIJA

SAŽETAK: Prirodni plin danas se smatra najvećim izvorom energije potrebne stambenim područjima i industriji. Pogled na tehnologije kojima se Iran koristi otkriva da su plinovodi najbolji i najsigurniji način za distribuciju prirodnog plina u zemlji. Ovaj izvor energije, koji se ponekad naziva čistim gorivom, ima stratešku ulogu u opskrbi potrebne energije. S druge strane, opskrba gorivom mora biti stalna, ali i sigurna. Stoga se zaključuje da su potrebne odgovarajuće mjere za upravljanje rizicima od curenja, požara i eksplozija na ovakvim postrojenjima. Za postizanje toga cilja najpotrebnije je ustanoviti uzroke nesreća i ispitati pouzdanost. Nadalje, neizbježno se mora procijeniti vjerojatnost događanja nesreće na cjevovodima. Jedan od ključnih koraka u procesu vrednovanja rizika jest procjena vjerojatnosti mogućih nesreća. Članak se koristi FTA (fault tree analysis) metodologijom za proučavanje načina procjene vjerojatnosti nesreća na cjevovodima za prirodni plin. Nadalje, ponuđena je i nova metoda temeljena na pridruživanju težina stablu kvarova, a 'what-if' (što-ako) scenarij služi za utvrđivanje opasnosti pri transportu prirodnog plina od njegova glavnog izvora. Na osnovi rezultata studije predlaže se da se vjerojatnost događanja nesreća na cjevovodima za prirodni plin kontrolira tehničkim i sustavnim pristupom kojim se utvrđuju i kontroliraju uzroci tih nesreća.

Ključne riječi: *vjerojatnost nesreće, pouzdanost, uzroci nesreća, ALOHA software, scenarij mlaznog požara*

Izvorni znanstveni rad
Primljeno: 2.9.2015.
Prihvaćeno: 4.1.2016.